

DECLARATION

I, Hiroshi MURANO of Maruman Building, 11-1, Nishi-Shinbashi 1-chome, Minato-ku, Tokyo, Japan hereby certify that I am a translator of the attached documents and familiar with English, and that the documents are true translation to the best of my knowledge and belief.

This 25th day of September, 2001.

A handwritten signature in black ink, appearing to read 'Hiroshi MURANO', written over a horizontal line.

Hiroshi MURANO

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THIN-FILM MAGNETIC HEAD AND MANUFACTURING METHOD OF  
THIN-FILM MAGNETIC HEAD

FIELD OF THE INVENTION

The present invention relates to a thin-film magnetic head provided with at least an inductive write head element and to a manufacturing method of the thin-film magnetic head.

DESCRIPTION OF THE RELATED ART

In a thin-film magnetic head provided with an inductive write head element, a thin-film coil conductor is extremely heated due to a write current flowing there through and thus its environmental temperature is greatly increased. However, in conventional thin-film magnetic heads, no effective countermeasure is taken against the rise in temperature due to the generated heat of the coil conductor. Most of the conventional heads only adopt a heat-radiation structure relaying entirely on heat conduction of the insulation material surrounding the coil conductor.

Japanese utility model publication No. 06084507A discloses thermal diffusion layers of BeO or Ag directly laminated on and contacted with an upper magnetic pole layer and a lower magnetic pole layer to restrain increase in temperature of the upper and lower magnetic pole layers.

However, such direct lamination of the metallic layer

on the upper and lower magnetic pole layers, although it is made of a non-magnetic metallic material, will have a detrimental effect on the magnetic characteristics of the head, and also will not provide sufficient heat-radiation effect to the upper and lower magnetic pole layers.

If the rise in temperature due to heating of the coil conductor increases in large amount, the insulation layer surrounding the coil conductor will thermally expand and jut toward an air bearing surface (ABS) of the head. This projection of the insulation layer may come into contact with a magnetic medium in operation of the head. Also, because of heating, the coil conductor itself may be disconnected.

Particularly, since a track width of the thin-film magnetic head becomes narrowed and the magnetic head itself becomes downsized to satisfy the requirement for ever increasing data storage capacities and densities in today's magnetic disk drive apparatus, it is very difficult to radiate the generated heat from the thin-film magnetic head. Also, since the space between the magnetic medium surface and the magnetic head is narrowed, occurrence of the projection of the insulation layer becomes significant problem. Furthermore, since there is the tendency to increase the coercive force  $H_c$  of the magnetic medium in order to enhance data storage densities and therefore the write current is becoming increasingly larger, heating of the coil conductor presents

serious problem.

#### SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a thin-film magnetic head and a manufacturing method of the head, whereby thermal expansion toward ABS of the head and disconnection of a coil conductor itself due to heating of the coil conductor can be effectively prevented.

According to the present invention, a thin-film magnetic head has an inductive write head element including an upper core layer with a front end section (end section of ABS side) magnetically coupling with an upper magnetic pole, a lower core layer with a front end section magnetically coupling with a lower magnetic pole, a coil conductor formed to pass between the upper core layer and the lower core layer, and an coil insulation layer for sandwiching the coil conductor. Particularly, according to the present invention, at least one thermal diffusion layer with a good thermal conductivity is formed on the coil insulation layer at an outside region of the upper core layer, or at least one thermal diffusion layer is formed at an outside region of the upper core layer to contact with a part of the coil conductor or to constitute a part of the coil conductor.

Since the thermal diffusion layer is formed at the outside region of the upper core layer, heat-radiation effect

can be expected without any deleterious effect on the magnetic performance of the inductive write head element. Also, since the thermal diffusion layer expands to cover the outside region of the upper core layer, within which region the most of the coil conductor is located, sufficient heat-radiation effect can be obtained. As a result, not only contact of the magnetic head with a magnetic medium in operation due to the thermal expansion toward the ABS but also disconnection of the coil conductor itself, caused by heating of the coil conductor, can be effectively prevented.

It is preferred that the thermal diffusion layer is formed at a rear (opposite to ABS side) outside region of the upper core layer, and/or that the thermal diffusion layer is formed at a lateral (lateral side seen from ABS) outside region of the upper core layer

It is also preferred that only a thin coating film is formed on the thermal diffusion layer to improve heat-radiation performance. In this case, the coating film may be made of a material selected from Ti, Cr, Ta, Ni, Fe, Co, Au, Pt, Rh and Ru, or an alloy containing at least Ti, Cr, Ta, Ni, Fe or Co.

It is preferred that the thermal diffusion layer is made of a material with a thermal conductivity higher than that of  $Al_2O_3$  and/or a material with a thermal expansion coefficient lower than that of  $Al_2O_3$ . The thermal diffusion

layer may be made of a material selected from Au, Ag, Si, Zn, Al, Ir, Cd, Sb, W, Ta, Fe, Pb, Ni, Pt, Pd, Mg and Mo, or an alloy containing at least one of Au, Ag, Si, Zn, Al, Ir, Cd, Sb, W, Ta, Fe, Pb, Ni, Pt, Pd, Mg and Mo.

The present invention also concerns to a manufacturing method of a thin-film magnetic head including a step of forming a lower core layer with a front end section magnetically coupling with a lower magnetic pole, a step of forming a first coil insulation layer at least on the lower core layer, a step of forming a coil conductor on the first coil insulation layer, having a pattern to pass on the lower core layer, a step of forming a second coil insulation layer on the coil conductor, and a step of forming an upper core layer with a front end section magnetically coupling with an upper magnetic pole, on the second coil insulation layer, or to a manufacturing method of a thin-film magnetic head including a step of forming a lower core layer with a front end section magnetically coupling with a lower magnetic pole, a step of forming a first coil insulation layer at least on the lower core layer, a step of forming a coil conductor on the first coil insulation layer, having a pattern to pass on the lower core layer, a step of forming a second coil insulation layer on the coil conductor, a step of forming a coil conductor on the second coil insulation layer, having a pattern to pass on the lower core layer, a step of forming a

third coil insulation layer on the coil conductor, and a step of forming an upper core layer with a front end section magnetically coupling with an upper magnetic pole, on the third coil insulation layer. Particularly, according to the present invention, at least one thermal diffusion layer with a good thermal conductivity is formed on the second coil insulation layer or on the third coil insulation layer at an outside region of the upper core layer.

It is preferred that the method further includes a step of forming bumps on connection terminals to be connected with the coil conductor, and that the thermal diffusion layer is formed in the step of forming the bumps. It is also preferred that the method further includes a step of forming under films for bumps formed on connection terminals to be connected with the coil conductor, and that the thermal diffusion layer is formed in the step of forming the under films. If the thermal diffusion layer is formed in the same forming process of the bumps or the under films for bumps, no additional process is required.

It is further preferred that the thermal diffusion layer is formed at a rear outside region and/or a lateral outside region of the upper core layer.

In a manufacturing method of a thin-film magnetic head according to the present invention, at least one thermal diffusion layer with a good thermal conductivity is formed at

an outside region of the upper core layer, so that the thermal diffusion layer is in contact with a part of the coil conductor or constitutes a part of the coil conductor.

In this case, it is preferred that the thermal diffusion layer is formed in the step of forming the coil conductor. If the thermal diffusion layer is formed in the same forming process of the coil conductor, no additional process is required.

It is also preferred that only a thin coating film is formed on the thermal diffusion layer to improve heat-radiation performance. In this case, the coating film may be made of a material selected from Ti, Cr, Ta, Ni, Fe, Co, Au, Pt, Rh and Ru, or an alloy containing at least Ti, Cr, Ta, Ni, Fe or Co.

It is preferred that the thermal diffusion layer is made of a material with a thermal conductivity higher than that of  $Al_2O_3$  and/or a material with a thermal expansion coefficient lower than that of  $Al_2O_3$ . The thermal diffusion layer may be made of a material selected from Au, Ag, Si, Zn, Al, Ir, Cd, Sb, W, Ta, Fe, Pb, Ni, Pt, Pd, Mg and Mo, or an alloy containing at least one of Au, Ag, Si, Zn, Al, Ir, Cd, Sb, W, Ta, Fe, Pb, Ni, Pt, Pd, Mg and Mo.

Further objects and advantages of the present invention will be apparent from the following description of the preferred embodiments of the invention as illustrated in the



accompanying drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a plane view schematically illustrating a single thin-film magnetic head formed on a wafer surface in a preferred embodiment according to the present invention;

Figs. 2a to 2g show plane views schematically illustrating an example of manufacturing processes of the thin-film magnetic head in the embodiment of Fig. 1;

Figs. 3a to 3g show sectional views along an A-A line of Figs. 2a to 2g, respectively;

Figs. 4a to 4g show plane views schematically illustrating another example of manufacturing processes of a thin-film magnetic head in a modification of the embodiment of Fig. 1;

Figs. 5a to 5g show sectional views along an A-A line of Figs. 4a to 4g, respectively;

Fig. 6 shows a plane view schematically illustrating a single thin-film magnetic head formed on a wafer surface in another embodiment according to the present invention;

Fig. 7 shows a plane view schematically illustrating a single thin-film magnetic head formed on a wafer surface in a further embodiment according to the present invention;

Fig. 8 shows a plane view schematically illustrating a single thin-film magnetic head formed on a wafer surface in a

still further embodiment according to the present invention;

Figs. 9a to 9g show plane views schematically illustrating an example of manufacturing processes of the thin-film magnetic head in the embodiment of Fig. 8; and

Figs. 10a to 10g show sectional views along an A-A line of Figs. 9a to 9g, respectively.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fig. 1 schematically illustrates a single thin-film magnetic head formed on a wafer surface in a preferred embodiment according to the present invention. In this embodiment, the thin-film magnetic head consists of a composite thin-film magnetic head provided with an inductive write head element and a magnetoresistive effect (MR) read head element.

In the figure, reference numerals 10a and 10b denote connection terminals or pads for the MR read head element, 11a and 11b denote lead conductors for the MR read head element, one ends of which are connected to the respective pads 10a and 10b, 12a and 12b denote contacts for the MR read head element, connected to the other ends of the respective lead conductors 11a and 11b, 13a and 13b denote MR lead electrodes connected to the respective contacts 12a and 12b, 14 denotes an MR film both end portions of which are connected to the respective MR lead electrodes 13a and 13b, 15a and 15b denote connection

terminals or pads for the inductive write head element, 16a and 16b denote lead conductors for the inductive write head element, one ends of which are connected to the respective pads 15a and 15b, 17 denotes a first layer coil conductor, one end of which is connected to the other end of the lead conductor 16a, 18 denotes a second layer coil conductor, one end of which is connected to the other end of the lead conductor 16b, 19 denotes a coil connection part for connecting the first layer coil conductor 17 and the second layer coil conductor 18 with each other, 20 denotes a coil insulation layer (a first coil insulation layer 20a, a second coil insulation layer 20b and a third coil insulation layer 20c) surrounding the first and second layer coil conductors 17 and 18, 21 denotes a lower shield layer, 22 denotes an upper shield layer doubling as a lower core layer (a first upper shield layer 22a and a second upper shield layer doubling as a lower core layer 22b), 23 denotes an upper core layer, 24 denotes a back gap part for magnetically connecting the lower core layer 22 and the upper core layer 23 in order to form a magnetic path, and 25 denotes a thermal diffusion layer laminated on the coil insulation layer 20 at the rear (opposite to ABS side) outside region of the upper core layer 23, respectively.

Figs. 2a to 2g schematically illustrate an example of manufacturing processes of the thin-film magnetic head in this

embodiment, and Figs. 3a to 3g illustrate sections along an A-A line of Figs. 2a to 2g, respectively. Hereinafter, the manufacturing processes of the thin-film magnetic head in this embodiment will be described with reference to these figures.

First, an under film and other necessary film are deposited on a wafer. Next, as shown in Figs. 2a and 3a, the lower shield layer 21 is formed on the under film, an insulation layer is deposited thereon, and then its surface is flattened by executing chemical mechanical polishing (CMP).

Then, as shown in Figs. 2b and 3b, a first read gap layer 26a is formed thereon, the MR film 14 and the MR lead electrodes 13a and 13b are formed, a second read gap layer 26b is formed thereon, and thereafter the first upper shield layer 22a is formed thereon.

Then, as shown in Figs. 2c and 3c, the second upper shield layer doubling as the lower core layer 22b is formed on the first upper shield layer 22a, an insulation layer is deposited thereon, and then its surface is flattened by executing CMP.

Thereafter, as shown in Figs. 2d and 3d, the first coil insulation layer 20a is deposited, the first layer coil conductor 17 and the coil connection part 19 are formed thereon, and then the second coil insulation layer 20b is formed to cover the first layer coil conductor 17.

Then, as shown in Figs. 2e and 3e, the second layer

coil conductor 18 and the coil connection part 19 are formed on the second coil insulation layer 20b, and the third coil insulation layer 20c is formed thereon. The pads 10a, 10b, 15a and 15b and the lead conductors 11a, 11b, 16a and 16b are formed in this stage.

Then, as shown in Figs. 2f and 3f, the upper core layer 23 is formed on the third coil insulation layer 20c at its front side (ABS side) region.

Thereafter, as shown in Figs. 2g and 3g, under films for bumps are formed on the pads 10a, 10b, 15a and 15b, and then bumps are formed on the under films. In the same process of forming the bumps, the thermal diffusion layer 25 is formed on the third coil insulation layer 20c at the rear (opposite to ABS side) outside region of the upper core layer 23.

The thermal diffusion layer 25 is made of a material with a higher thermal conductivity than that of a protection layer of  $Al_2O_3$ . Preferably, the thermal diffusion layer 25 is made of the same material as the bumps such as Cu for example in order to simplify the manufacturing process. However, as for the thermal diffusion layer 25, any material selected from Au, Ag, Si, Zn, Al, Ir, Cd, Sb, W, Ta, Fe, Pb, Ni, Pt, Pd, Mg and Mo or an alloy containing at least one of these materials can be used. It is also preferred to use as the thermal diffusion layer 25 a material with a lower thermal expansion coefficient than that of a protection layer of  $Al_2O_3$ .

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Although it is not shown in the figures, thereafter, the protection layer such as  $Al_2O_3$  is formed on the upper core layer 23 and the thermal diffusion layer 25. If no protection layer is formed but only a thin coating film is formed on the thermal diffusion layer 25, the heat-radiation effect will be more improved. This coating film will be made of a material selected from Ti, Cr, Ta, Ni, Fe, Co, Au, Pt, Rh and Ru or an alloy containing at least Ti, Cr, Ta, Ni, Fe or Co.

As aforementioned, according to this embodiment, since the thermal diffusion layer 25 is formed on the third coil insulation layer 20c at the rear outside region of the upper core layer 23, heat-radiation effect can be expected without any deleterious effect on the magnetic performance of the inductive write head element. Also, since the thermal diffusion layer 25 expands to cover the outside region of the upper core layer 23, within which region the most of the coil conductors 17 and 18 are located, sufficient heat-radiation effect can be obtained. As a result, not only contact of the magnetic head with a magnetic medium in operation due to the heat expansion toward the ABS but also disconnection of the coil conductors 17 and 18 themselves, caused by heating of the coil conductors 17 and 18, can be effectively prevented.

Furthermore, according to this embodiment, the thermal diffusion layer 25 is formed in the same forming process of the bumps, no additional process is required. Also, as the

thermal diffusion layer 25 can be made thick as well as the bumps, greater thermal radiation and thermal storage effect can be expected.

It should be noted that each layer except for the thermal diffusion layer 25, the protection layer and the coating film can be made of any material generally used in this technical field, and can be formed (deposited, patterned) by using any method known in this field.

Although in this embodiment the upper shield layer doubling as the lower core layer 22 is formed in the two layer structure of the first upper shield layer 22a and the second upper shield layer doubling as the lower core layer 22b, it is possible to form it in a single layer structure. In this embodiment the coil conductor is formed also in the two layer structure of the first layer coil conductor 17 and the second layer coil conductor 18. Nevertheless, the coil conductor may be formed in a multilayer structure of more than two layers or in a single layer structure.

Figs. 4a to 4g schematically illustrate another example of manufacturing processes of a thin-film magnetic head in a modification of the embodiment of Fig. 1, and Figs. 5a to 5g illustrate sections along an A-A line of Figs. 4a to 4g, respectively. Hereinafter, the manufacturing processes of the thin-film magnetic head in this modification will be described with reference to these figures. In the modification of Figs.

4a to 4g and Figs. 5a to 5g, the same elements as these in the embodiment of Fig. 1, Figs. 2a to 2g and Figs. 3a to 3g use the same reference numerals, respectively.

First, an under film and other necessary film are deposited on a wafer. Next, as shown in Figs. 4a and 5a, the lower shield layer 21 is formed on the under film, an insulation layer is deposited thereon, and then its surface is flattened by executing CMP.

Then, as shown in Figs. 4b and 5b, a first read gap layer 26a is formed thereon, the MR film 14 and the MR lead electrodes 13a and 13b are formed, a second read gap layer 26b is formed thereon, and thereafter the first upper shield layer 22a is formed thereon.

Then, as shown in Figs. 4c and 5c, the second upper shield layer doubling as the lower core layer 22b is formed on the first upper shield layer 22a, an insulation layer is deposited thereon, and then its surface is flattened by executing CMP.

Thereafter, as shown in Figs. 4d and 5d, the first coil insulation layer 20a is deposited, the first layer coil conductor 17 and the coil connection part 19 are formed thereon, and then the second coil insulation layer 20b is formed to cover the first layer coil conductor 17.

Then, as shown in Figs. 4e and 5e, the second layer coil conductor 18 and the coil connection part 19 are formed



on the second coil insulation layer 20b, and the third coil insulation layer 20c is formed thereon. The pads 10a, 10b, 15a and 15b and the lead conductors 11a, 11b, 16a and 16b are formed in this stage.

Then, as shown in Figs. 4f and 5f, the upper core layer 23 is formed on the third coil insulation layer 20c at its front side (ABS side) region.

Thereafter, as shown in Figs. 4g and 5g, under films for bumps are formed on the pads 10a, 10b, 15a and 15b. In the same process of forming the under films for bumps, a thermal diffusion layer 55 is formed on the third coil insulation layer 20c at the rear (opposite to ABS side) outside region of the upper core layer 23. Thus, the thermal diffusion layer 55 in this modification is thinner than the thermal diffusion layer 25 in the embodiment of Fig. 1, Figs. 2a to 2g and Figs. 3a to 3g.

The thermal diffusion layer 55 is made of a material with a higher thermal conductivity than that of a protection layer of  $\text{Al}_2\text{O}_3$ . Preferably, the thermal diffusion layer 55 is made of the same material as the under films for bumps such as Cu for example in order to simplify the manufacturing process. However, as for the thermal diffusion layer 55, any material selected from Au, Ag, Si, Zn, Al, Ir, Cd, Sb, W, Ta, Fe, Pb, Ni, Pt, Pd, Mg and Mo or an alloy containing at least one of these materials can be used. It is also preferred to use as

the thermal diffusion layer 55 a material with a lower thermal expansion coefficient than that of a protection layer of  $\text{Al}_2\text{O}_3$ .

Although it is not shown in the figures, thereafter, on the under films formed on the pads 10a, 10b, 15a and 15b, bumps are formed. Then, the protection layer such as  $\text{Al}_2\text{O}_3$  is formed on the upper core layer 23 and the thermal diffusion layer 55. If no protection layer is formed but only a thin coating film is formed on the thermal diffusion layer 55, the heat-radiation effect will be more improved. This coating film will be made of a material selected from Ti, Cr, Ta, Ni, Fe, Co, Au, Pt, Rh and Ru or an alloy containing at least Ti, Cr, Ta, Ni, Fe or Co.

Operations and advantages in this modification are the same as those in the embodiment of Fig. 1, Figs. 2a to 2g and Figs. 3a to 3g.

It should be noted that each layer except for the thermal diffusion layer 55, the protection layer and the coating film can be made of any material generally used in this technical field, and can be formed (deposited, patterned) by using any method known in this field.

Although in this modification the upper shield layer doubling as the lower core layer 22 is formed in the two layer structure of the first upper shield layer 22a and the second upper shield layer doubling as the lower core layer 22b, it is possible to form it in a single layer structure. In this

modification the coil conductor is formed also in the two layer structure of the first layer coil conductor 17 and the second layer coil conductor 18. Nevertheless, the coil conductor may be formed in a multilayer structure of more than two layers or in a single layer structure.

Fig. 6 schematically illustrates a single thin-film magnetic head formed on a wafer surface in another embodiment according to the present invention. In this embodiment, the thin-film magnetic head consists of a composite thin-film magnetic head provided with an inductive write head element and an MR read head element. In the embodiment, the same elements as these in the embodiment of Fig. 1, Figs. 2a to 2g and Figs. 3a to 3g use the same reference numerals, respectively.

In the figure, reference numerals 10a and 10b denote connection terminals or pads for the MR read head element, 11a and 11b denote lead conductors for the MR read head element, one ends of which are connected to the respective pads 10a and 10b, 12a and 12b denote contacts for the MR read head element, connected to the other ends of the respective lead conductors 11a and 11b, 13a and 13b denote MR lead electrodes connected to the respective contacts 12a and 12b, 14 denotes an MR film both end portions of which are connected to the respective MR lead electrodes 13a and 13b, 15a and 15b denote connection terminals or pads for the inductive write head element, 16a

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and 16b denote lead conductors for the inductive write head element, one ends of which are connected to the respective pads 15a and 15b, 17 denotes a first layer coil conductor, one end of which is connected to the other end of the lead conductor 16a, 18 denotes a second layer coil conductor, one end of which is connected to the other end of the lead conductor 16b, 19 denotes a coil connection part for connecting the first layer coil conductor 17 and the second layer coil conductor 18 with each other, 20 denotes a coil insulation layer surrounding the coil conductors 17 and 18, 21 denotes a lower shield layer, 22 denotes an upper shield layer doubling as a lower core layer, 23 denotes an upper core layer, 24 denotes a back gap part for magnetically connecting the lower core layer 22 and the upper core layer 23 in order to form a magnetic path, and 65a and 65b denote thermal diffusion layers laminated on the coil insulation layer 20 at the lateral outside regions of the upper core layer 23, respectively.

The manufacturing processes of the thin-film magnetic head in this embodiment are the substantially same as those shown in Figs. 2a to 2g and Figs. 3a to 3g and in Figs. 4a to 4g and Figs. 5a to 5g.

In the embodiment, since the thermal diffusion layers 65a and 65b broadly expand to cover the side outside regions of the upper core layer 23, more larger thermal radiation and

thermal storage effect can be expected. Other configurations, operations and advantages in this modification are the same as those in the embodiment of Fig. 1, Figs. 2a to 2g and Figs. 3a to 3g and in the modification of Figs. 4a to 4g and Figs. 5a to 5g.

Fig. 7 schematically illustrates a single thin-film magnetic head formed on a wafer surface in a further embodiment according to the present invention. In this embodiment, the thin-film magnetic head consists of a composite thin-film magnetic head provided with an inductive write head element and an MR read head element. In the embodiment, the same elements as these in the embodiment of Fig. 1, Figs. 2a to 2g and Figs. 3a to 3g use the same reference numerals, respectively.

In the figure, reference numerals 10a and 10b denote connection terminals or pads for the MR read head element, 11a and 11b denote lead conductors for the MR read head element, one ends of which are connected to the respective pads 10a and 10b, 12a and 12b denote contacts for the MR read head element, connected to the other ends of the respective lead conductors 11a and 11b, 13a and 13b denote MR lead electrodes connected to the respective contacts 12a and 12b, 14 denotes an MR film both end portions of which are connected to the respective MR lead electrodes 13a and 13b, 15a and 15b denote connection terminals or pads for the inductive write head element, 16a

and 16b denote lead conductors for the inductive write head element, one ends of which are connected to the respective pads 15a and 15b, 17 denotes a first layer coil conductor, one end of which is connected to the other end of the lead conductor 16a, 18 denotes a second layer coil conductor, one end of which is connected to the other end of the lead conductor 16b, 19 denotes a coil connection part for connecting the first layer coil conductor 17 and the second layer coil conductor 18 with each other, 20 denotes a coil insulation layer surrounding the coil conductors 17 and 18, 21 denotes a lower shield layer, 22 denotes an upper shield layer doubling as a lower core layer, 23 denotes an upper core layer, 24 denotes a back gap part for magnetically connecting the lower core layer 22 and the upper core layer 23 in order to form a magnetic path, and 75 denotes a thermal diffusion layer laminated on the coil insulation layer 20 at the rear outside region of and the lateral outside regions of the upper core layer 23, respectively.

The manufacturing processes of the thin-film magnetic head in this embodiment are the substantially same as those shown in Figs. 2a to 2g and Figs. 3a to 3g and in Figs. 4a to 4g and Figs. 5a to 5g.

In the embodiment, since the thermal diffusion layer 75 more broadly expand to cover not only the rear outside region of but also the side outside regions of the upper core layer

23, extremely larger thermal radiation and thermal storage effect can be expected. Other configurations, operations and advantages in this modification are the same as those in the embodiment of Fig. 1, Figs. 2a to 2g and Figs. 3a to 3g, in the modification of Figs. 4a to 4g and Figs. 5a to 5g, and in the embodiment of Fig. 6.

Fig. 8 schematically illustrates a single thin-film magnetic head formed on a wafer surface in a still further embodiment according to the present invention. In this embodiment, the thin-film magnetic head consists of a composite thin-film magnetic head provided with an inductive write head element and an MR read head element. In the embodiment, the same elements as these in the embodiment of Fig. 1, Figs. 2a to 2g and Figs. 3a to 3g use the same reference numerals, respectively.

In the figure, reference numerals 10a and 10b denote connection terminals or pads for the MR read head element, 11a and 11b denote lead conductors for the MR read head element, one ends of which are connected to the respective pads 10a and 10b, 12a and 12b denote contacts for the MR read head element, connected to the other ends of the respective lead conductors 11a and 11b, 13a and 13b denote MR lead electrodes connected to the respective contacts 12a and 12b, 14 denotes an MR film both end portions of which are connected to the respective MR lead electrodes 13a and 13b, 15a and 15b denote connection

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terminals or pads for the inductive write head element, 16a and 16b denote lead conductors for the inductive write head element, one ends of which are connected to the respective pads 15a and 15b, 17 denotes a first layer coil conductor, one end of which is connected to the other end of the lead conductor 16a, 18 denotes a second layer coil conductor, one end of which is connected to the other end of the lead conductor 16b, 19 denotes a coil connection part for connecting the first layer coil conductor 17 and the second layer coil conductor 18 with each other, 20 denotes a coil insulation layer (a first coil insulation layer 20a, a second coil insulation layer 20b and a third coil insulation layer 20c) surrounding the first and second layer coil conductors 17 and 18, 21 denotes a lower shield layer, 22 denotes an upper shield layer doubling as a lower core layer (a first upper shield layer 22a and a second upper shield layer doubling as a lower core layer 22b), 23 denotes an upper core layer, 24 denotes a back gap part for magnetically connecting the lower core layer 22 and the upper core layer 23 in order to form a magnetic path, and 85 denotes a thermal diffusion layer laminated on the coil insulation layer 20 at the lateral outside region of the upper core layer 23 so as to directly contact with the first layer coil conductor 17 or to constitute a part of the first layer coil conductor 17, respectively. In modification, the thermal diffusion layer 85



may be formed so as to directly contact with the second layer coil conductor 18 or to constitute a part of the second layer coil conductor 18.

Figs. 9a to 9g schematically illustrate an example of manufacturing processes of the thin-film magnetic head in this embodiment, and Figs. 10a to 10g illustrate sections along an A-A line of Figs. 9a to 9g, respectively. Hereinafter, the manufacturing processes of the thin-film magnetic head in this embodiment will be described with reference to these figures.

First, an under film and other necessary film are deposited on a wafer. Next, as shown in Figs. 9a and 9a, the lower shield layer 21 is formed on the under film, an insulation layer is deposited thereon, and then its surface is flattened by executing CMP.

Then, as shown in Figs. 9b and 10b, a first read gap layer 26a is formed thereon, the MR film 14 and the MR lead electrodes 13a and 13b are formed, a second read gap layer 26b is formed thereon, and thereafter the first upper shield layer 22a is formed thereon.

Then, as shown in Figs. 9c and 10c, the second upper shield layer doubling as the lower core layer 22b is formed on the first upper shield layer 22a, an insulation layer is deposited thereon, and then its surface is flattened by executing CMP.

Thereafter, as shown in Figs. 9d and 10d, the first

coil insulation layer 20a is deposited, the first layer coil conductor 17 and the coil connection part 19 are formed thereon. In the same process of forming the first layer coil conductor 17 and the coil connection part 19, the thermal diffusion layer 85 is formed on the first coil insulation layer 20a at the lateral outside region of the upper core layer 23 so as to directly contact with the first layer coil conductor 17 or to constitute a part of the first layer coil conductor 17. Then, the second coil insulation layer 20b is formed to cover the first layer coil conductor 17 and the thermal diffusion layer 85.

The thermal diffusion layer 85 is made of a material with a higher thermal conductivity than that of a protection layer of  $\text{Al}_2\text{O}_3$ . Preferably, the thermal diffusion layer 85 is made of the same material as the coil conductor such as Cu for example in order to simplify the manufacturing process.

However, as for the thermal diffusion layer 85, any material selected from Au, Ag, Si, Zn, Al, Ir, Cd, Sb, W, Ta, Fe, Pb, Ni, Pt, Pd, Mg and Mo or an alloy containing at least one of these materials can be used. It is also preferred to use as the thermal diffusion layer 85 a material with a lower thermal expansion coefficient than that of a protection layer of  $\text{Al}_2\text{O}_3$ .

insulation layer 20c is formed thereon. The pads 10a, 10b, 15a and 15b and the lead conductors 11a, 11b, 16a and 16b are formed in this stage. In the same process of forming the second layer coil conductor 18 and the coil connection part 19, the thermal diffusion layer 85 may be formed at the lateral outside region of the upper core layer 23 so as to directly contact with the second layer coil conductor 18 or to constitute a part of the second layer coil conductor 18. Namely, the thermal diffusion layer 85 may be formed in the same process of forming the first layer coil conductor 17 or in the same process of forming the second layer coil conductor 18. In further modification, one thermal diffusion layer may be formed in the same process of forming the first layer coil conductor 17, and the other thermal diffusion layer may be formed in the same process of forming the second layer coil conductor 18.

Then, as shown in Figs. 9f and 10f, the upper core layer 23 is formed on the third coil insulation layer 20c at its front side (ABS side) region.

Thereafter, as shown in Figs. 9g and 10g, under films for bumps are formed on the pads 10a, 10b, 15a and 15b, and then bumps are formed on the under films.

Although it is not shown in the figures, thereafter, the protection layer such as  $\text{Al}_2\text{O}_3$  is formed on the upper core layer 23 and the third coil insulation layer 20c.

As aforementioned, according to this embodiment, since the thermal diffusion layer 85 is formed at the lateral outside region of the upper core layer 23, heat-radiation effect can be expected without any deleterious effect on the magnetic performance of the inductive write head element. Also, since the thermal diffusion layer 85 is formed so as to directly contact with the first and/or second layer coil conductors, or to constitute a part of the first and/or second layer coil conductors, sufficient heat-radiation effect can be obtained. As a result, not only contact of the magnetic head with a magnetic medium in operation due to the heat expansion toward the ABS but also disconnection of the coil conductors 17 and 18 themselves, caused by heating of the coil conductors 17 and 18, can be effectively prevented.

Furthermore, according to this embodiment, the thermal diffusion layer 85 is formed in the same forming process of the coil conductor, no additional process is required.

It should be noted that each layer except for the thermal diffusion layer 85 and the protection layer can be made of any material generally used in this technical field, and can be formed (deposited, patterned) by using any method known in this field.

Although in this embodiment the upper shield layer doubling as the lower core layer 22 is formed in the two layer structure of the first upper shield layer 22a and the second

upper shield layer doubling as the lower core layer 22b, it is possible to form it in a single layer structure. In this embodiment the coil conductor is formed also in the two layer structure of the first layer coil conductor 17 and the second layer coil conductor 18. Nevertheless, the coil conductor may be formed in a multilayer structure of more than two layers or in a single layer structure.

It is apparent that the MR read head element in the composite thin-film magnetic head may be an anisotropic magnetoresistive effect (AMR) read head element, a giant magnetoresistive effect (GMR) read head element including both a current in plane (CIP) type GMR element in which current flows along layer planes and a current perpendicular to plane (CPP) type GMR element in which current flows perpendicular to layer planes, or a tunnel magnetoresistive effect (TMR) read head element.

It will be also noted that the present invention is not limited to a composite thin-film magnetic head provided with an inductive write head element and an MR read head element but can be applied to a thin-film magnetic head provided with only an inductive write head element or an inductive read/write head element.

Many widely different embodiments of the present invention may be constructed without departing from the spirit and scope of the present invention. It should be understood

that the present invention is not limited to the specific  
embodiments described in the specification, except as defined  
in the appended claims.